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Design and Experimental Research of New Type Brake by Wire System Based on Giant-magnetostrictive Material

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Abstract: In this paper, H type brake by wire system based on giant-magnetostrictive material is designed from two aspects of hardware and software. System principle prototype is manufactured. Hardware circuit mainly includes the Sepic circuit, current detection circuit, over current protection circuit, PWM driver protection circuit. Circuit parameters can be obtained through by theoretical calculation. Pedal sensor signal is taken as main control variable, look-up table method is used for brake by wire system. The experimental results show that the system can meet the braking requirements. It proves the feasibility of the scheme. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Brake by wire, Giant-magnetostrictive material, Control, Automobile.

1. Introduction

With the use of electronic control technology in braking system, brake by Wire system is the development direction in the future. Brake by wire system is mainly composed of pedal module, communication network module, the electronic control unit, motor brake module, power supply module, etc. Mechanical or hydraulic connections among module are removed. Compared with anti-lock braking system, brake by wire system has advantages of automotive lightweighting, passive safety enhancement, reduce assembly costs, environmental protection, easy maintenance and instant reaction.

Professor Li introduced the structure and working principle of electronic mechanical brake by wired system, key technology and development direction of brake by wire system were discussed[1].Pedal force simulation research of brake by wire system was carried out by A. Hildebrandt and, A. M. Harsha [2, 3]. Sohel Anwar adopted nonlinear sliding mode control method to control brake by wire system on low adhesion coefficient road surface, system noise and vibration was reduced [4]. W. Xiang, used fuzzy logic control method to control lateral stability and yawing stability of brake by wire system [5]. Simulation research of pedal force has been made , it provided a basis for the simulation design of pedal force. [6]. Brake by wired system design and development method was presented by M. Roberts and T. Chhaya [7].

Most of existing brake by wire system used motor as braking power and supplemented by retarding mechanism and motion transformation mechanism. Retarding mechanism and motion transformation mechanism commonly consist of planetary gear reducer and ball screw. This structure significantly increased the complexity of the actuator and assembly costs. At the same time, actuator response time of braking system is increased as a result of the existence of transmission mechanism. Based on above reasons, active safety performance of electronic mechanical brake by wire system should be further improved.

In this paper, H type brake by wire system based on giant-magnetostrictive material is designed from two aspects of hardware and software. System principle prototype is manufactured. Hardware circuit mainly includes the Sepic circuit, current detection circuit, over current protection circuit, PWM driver protection circuit. Circuit parameters can be obtained through by theoretical calculation. Pedal sensor signal is taken as main control variable, look-up table method is used for brake by wire system. The experimental results show that the system can meet the braking requirements. It proves the feasibility of the scheme. This work provides a new idea for researching automobile brake by wire system.

2. System Structure and Working Principle

The braking system adopts H type structure. Giant-magnetostrictive material rod is used as braking power. The GMM rod generates axial displacement under the action of magnetic field coming from electromagnetic coil. Axial displacement pushes the compliant mechanism and friction plate clamps the brake disc. System structure is shown in Fig. 1.

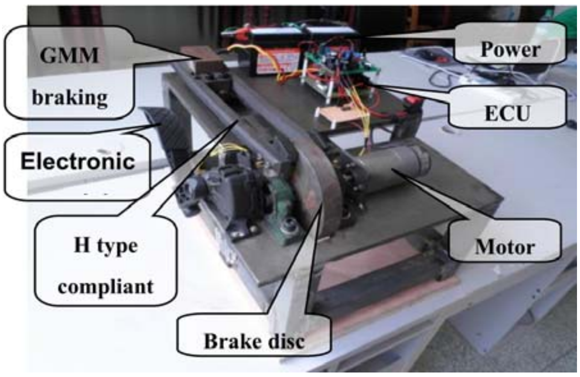

Fig. 1. H type structure of braking system.

Main indexes of GMM rod are shown in Table 1. Main indexes of compliant mechanism and drive coil are shown in Table 2.

3. Control System Design

ATmega8 is chosen as AVR single chip microcomputer. Internal of ATmega8 integrated with large capacity memory chips and hardware interface circuit. ATmega8 main indexes are shown in Table 3.

Table 1. Main indexes of GMM rod.

Parameters	Parameter values/unit	Parameters	Parameter values/unit
Giant-magnetostrictive rate	0.04×10^{-6} (m/A)	Magnetic field strength	0~80 (KA/M)
Young modulus	(2.5~3.5) ×1010 (N/m^2)	GMM rod output force	0~2000 N)
Coefficient of thermal expansion	8×10^{6} (1/°C)	Number of turns	1350 (turns)
The Curie temperature	380 (°C)	Bias magnetic field strength	20000 (H)
GMM rod size	Φ20×50 (mm×mm)	GMM rod Under Pressure	200~700 (MPa)
Magnetic permeability	3~15 (None)	GMM rod maximum stroke	280 (μm)

Table 2. Parameters of H type BBW.

Compliant mechanism		Drive coil	
Thickness	3.5 (mm)	Number of turns	1350
Arc radius	8.25 (mm)	Wire diameter	0.8 (mm)
Width	25 (mm)	Length	39 (mm)
Height	19 (mm)	Inner diameter	16.05 (mm)
Proportion	1/3	External diameter	38 (mm)

Table 3. Main indexes of ATmega8.

Parameters	Parameter values/unit	Parameters	Parameter values/unit
Single clock cycle instruction	130 (None)	PWM channel	3 (None)
8 byte general register	32 (None)	A/D conversion	8 (None)
Flash program memory	8K (byte)	I/O port	23 (None)
E2PROM	512 (byte)	Working voltage	2.7-5.5 (V)
Internal SRAM	1K (byte)	Computer program running speed	0-8 (MHz)
Independent oscillator	1 (None)		

3.1. Control System Circuit Design

Sepic converter structure is shown in Fig. 2.

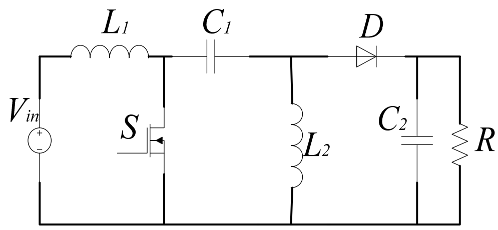

Fig. 2. Sepic converter structure

At present, vehicle power supply is commonly 12 V or 24 V. In order to get the appropriate output voltage, Sepic circuit was chosen as GMM's power source. In order to determine the circuit various components parameter values, Sepic circuit parameters were calculated as follows.

3.2. Computing the Input Inductor

$$L_1 = L_2 = L = \frac{V_{IN(min)}}{\Delta I_L \times F_{SW}} \times D_{max}, \tag{1}$$

where F_{sw} is the switching frequency, $D_{\max}$ is the duty-cycle correspond to $V_{IN(\min)}$.

Peak current which is used to maintain inductance is not saturated, it can be calculated as follows.

$$I_{L1(peak)} = I_{OUT} \times \frac{V_{OUT}}{V_{IN(min)}} \times (1 + \frac{40\%}{2}), \tag{2}$$

$$I_{L2(peak)} = I_{OUT} \times (1 + \frac{40\%}{2}), \tag{3}$$

If L1 and L2 reel in the same magnetic core, inductance value can be used instead of 2L because of the mutual inductance. Inductance value can be calculated as follows.

$$L1' = L2' = \frac{L}{2} = \frac{V_{IN(\min)}}{2 \times \Delta I_L \times F_{SW}} \times D_{\max} \tag{4}$$

3.3. Power Selection of MOSFET

Minimum threshold voltage Vin(max), on resistance RDS(ON), gate-drain charge QGD and maximum drain voltage VDS(max) are key parameters to choose MOSFET.

Peak switching current can be:

$$I_{Q1(peak)} = I_{L1(peak)} + I_{L2(peak)}, \tag{5}$$

Root-Mean-Square (RMS) of current flowing through the switch can be calculated as follows.

$$I_{Q1(RMS)} = I_{OUT} \sqrt{\frac{(V_{OUT} + V_{IN(\min)}) \times V_{OUT}}{V_{IN(\min)}}} \tag{6}$$

Dissipation power of MOSFET (PQ1) can be calculated as follows.

$$P_{Q1} = I^2_{Q1(RMS)} \times R_{DS(ON)} \times D_{\max} + (V_{IN(\min)} + V_{OUT}) \times I_{Q1(peak)} \times \frac{Q_{GD} \times F_{SW}}{I_g} \tag{7}$$

Dissipation power of MOSFET includes conduction loss and switching loss. Ig-Gate drive current. RDS(ON) value should be chosen when junction temperature reaches maximum value. We can find it in MOSFET data handbook. We must ensure conduction loss and switch loss does not exceed the encapsulation rating or exceed the limit of the cooling device.

3.4. Output Diode Selection

The diode should withstand peak current and backward voltage. In Sepic circuit, peak current of diode is equal to switch peak current. The minimum peak backward voltage that the diode must withstand can be calculated as follows.

$$V_{RD1} = V_{IN} + V_{OUT} \tag{8}$$

Schottky diode is used in order to improve efficiency.

3.5. Coupling Capacitance Selection of MOSFET

Coupling capacitance selection of Sepic is mainly based on the RMS current, it can be calculated as follows.

$$I_{Cs(RMS)} = I_{OUT} \times \sqrt{\frac{V_{OUT}}{V_{IN(\min)}}} \tag{9}$$

Voltage rating of coupling capacitance must be higher than the maximum input voltage. Coupling capacitance of the ripple voltage peak value can be calculated as follows.

$$\Delta V_{Cs} = \frac{I_{OUT} \times D_{\max}}{C_S \times F_{SW}}, \tag{10}$$

3.6. Selection of Output Capacitance

When the power switch is opened, output current is provided by the output capacitance. In order to avoid producing ripple current, the selected output capacitance must be able to provide the biggest effective current. Effective current of output capacitance can be calculated as follows.

$$I_{Cout(RMS)} = I_{OUT} \times \sqrt{\frac{V_{OUT}}{V_{IN(\min)}}}, \tag{11}$$

If half of ripple wave is relevant to Equivalent Series Resistance (ESR), another half of ripple wave is relevant to capacity. ESR and output capacitance can be calculated as follows.

$$ESR \leq \frac{V_{ripple} \times 0.5}{I_{L1(peak)} + I_{L2(peak)}}, \tag{12}$$

$$C_{OUT} \geq \frac{I_{OUT}}{V_{ripple} \times 0.5 \times F_{SW}}, \tag{13}$$

Output capacitance must meet the needs of effective current, ESR and capacity.

3.7. Selection of Input Capacitance

Effective current of input capacitance can be calculated as follows.

$$I_{CIN(RMS)} = \frac{\Delta I_L}{\sqrt{12}}, \tag{14}$$

Input capacitance must be able to withstand effective current.

Circuit related parameters can be calculated according to the formula from (1) to (14).

Root-Mean-Square of Current:

$$I_{Q1(RMS)} = 5 \times \sqrt{\frac{(40+24+0.5)\times(40+0.5)}{24^2}} = 10.65A$$

Maximum duty-cycle:

$$D_{\max} = \frac{40 + 0.5}{24 + 40 + 0.5} = 0.6279$$

Input inductor L_1, L_2:

$$L_1 = L_2 = L = \frac{24}{2.667 \times 20k} \times 0.6279 = 282.52uH$$

Peak current of inductor:

$$I_{L1(peak)} = 5 \times \frac{40+0.5}{24} \times 1.2 = 10.125A$$

$$I_{L2(peak)} = 5 \times 1.2 = 6A$$

Peak switching current:

$$I_{Q1(peak)} = 10.125 + 6 = 16.125A$$

Capacitance:

$$C_{OUT} \geq \frac{5 \times 0.6279}{0.02 \times 40 \times 0.5 \times 20\text{K}} = 392.4uF$$

$$C_{OUT} \geq \frac{5 \times 0.6279}{0.02 \times 40 \times 0.5 \times 20\text{K}} = 392.4uF$$

Finally selected circuit parameters are as follows.

Diode-MUR1560, inductance L_1=L_2=283 uH, capacitance C1=C2=10uF, switch tube-IGBT H30T90.

Relationship between input voltage and output voltage of Sepic circuit can be expressed as follows.

$$V_{OUT} = \frac{D}{1-D} V_{IN}, \tag{15}$$

Relationship between duty-cycle and output voltage can be expressed in Table 4.

Table 4. Relationship between duty-cycle and output voltage.

Serial number	Input signal duty-cycle	Output voltage (V)
1	0.1	2
2	0.2	6
3	0.3	10
4	0.4	16
5	0.5	24
6	0.6	36
7	0.65	40

3.8. Control System Hardware Circuit Design

MEGA8 single-chip computer receives and monitoring pedal sensor signal. Dc power supply output voltage and output current were adjusted through by changing the pulse width modulator (PWM) duty-cycle. GMM coil input current and voltage were adjusted in order to realize braking. Hardware circuit is mainly consists of current detection circuit, over current protection circuit, PWM driver protection circuit.

3.9. Control System Software Design

In order to simplify the control system software design, look-up table method is used for brake by wire system based on GMM. Pedal sensor signal is taken as main control variable. Pedal sensor signal is divided into several sections which are shown in Table 5.

Table 5. Relationship between input signal and output signal.

Serial number	Sensor signal range (V)	DC power supply output voltage (V)
1	0-0.5	0-3
2	0.5-1	3-5
3	1-1.5	5-8
4	1.5-2	8-12
5	2-2.5	12-16
6	2.5-3	16-20
7	3-3.5	20-25
8	3.5-4	25-30
9	4-4.5	30-32
10	4.5-5	32-34

4. System Performance Test

Testing program: take maximum current (4A) as benchmark, GMM rod displacement is tested through by changing current values. Experiment is divided into three groups, each group is tested two times that are No-load test and load test.

Test equipment: voltmeter, oscilloscope, electronic pedal, dial indicator, driving source, H type compliant mechanism.

First, second and third group testing data is shown in Fig. 3, Fig. 4 and Fig. 5.

The test shows that mean value of GMM rod maximum displacement under load condition is 158.7 um. At the same time, because the GMM rod output force range is 0-2000N, H type brake by wire system based on GMM can meet the requirements of braking.

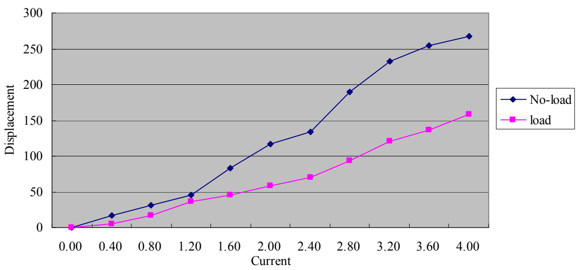

Fig .3. First group testing data.

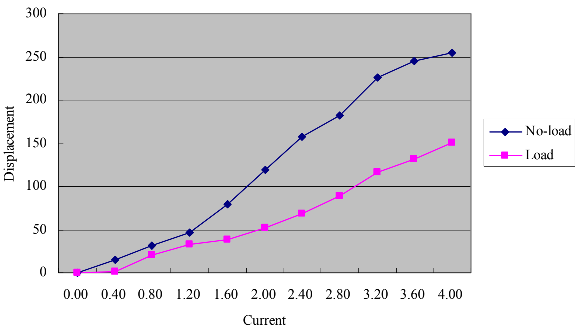

Fig. 4. Second group testing data.

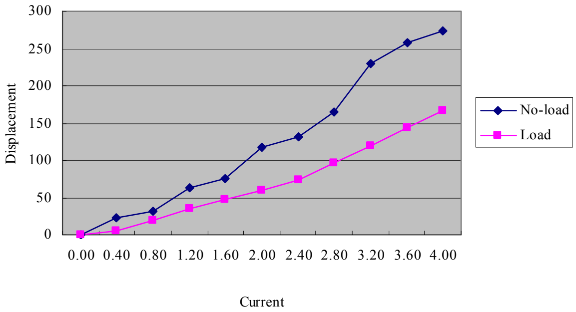

Fig. 5. Third group testing data.

5. Conclusions

In this paper, H type brake by wire system based on GMM is designed from two aspects of hardware and software. Tests of system prototype have been done. From the experimental results, the system can meet the braking requirements. It proves the feasibility of the scheme.

In the next step of research program, studies are focus on system compact and anti-lock braking system performance.

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References

[1]. Lin Yi, Shen Chen, Wang Jun, Automotive by-wire control technology and development, *Automobile Technology*, 2005, 12, pp. 1-3.

[2]. A. Hildebrandt, O. Sawodny, R. Trutschel, K. Augsburg, Nonlinear control design for implementation of specific pedal feeling in brake-by-wire car design concepts, in *Proceedings of the American Control Conference*, Vol. 2, 2004, pp. 1463-1468.

[3]. A. M. Harsha, S. Abeykoon, K. Ohnishi, Implementation of pedal feeling for brake by wire system using bilateral control, in *Proceedings of the IEEE International Symposium on Industrial Electronics*, 2008, pp. 1347-1352.

[4]. Sohel Anwar, Anti-lock braking control of a hybrid brake by wire system, *Institutions of Mechanical Engineers IMechE Proceedings*, 2006, Vol. 220, pp. 1101-1117.

[5]. W. Xiang, P. C. Richardson, C. Zhao, S. Mohammad, Automobile brake-by-wire control system design and analysis, *IEEE Transactions on Vehicular Technology*, Vol. 57, Issue 1, January 2008, pp. 138-145.

[6]. Zheng Hong-Yu, Zong Chang-fu, Gao Yue, Zhu Tian-Jun, Tian Cheng-Wei, Research on pedal force

simulation for brake-by-wire system, *Journal of System Simulation*, 2008, 20, 4, pp.1016-1019.

[7]. M. Roberts, T. Chhaya, An approach to the safety design and development of a brake by wire control system, in *Proceedings of the SAE World Congress and Exhibition*, 2011.
